Forum for Electromagnetic Research Methods and Application Technologies (FERMAT)

Inclined Slot Coupled Hemispherical Dielectric Resonator Antenna

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Abstract

Parametric variation of a microstrip line coupled dielectric resonator antenna with an inclined and offset slot in the common ground plane has been analyzed. Excitation of the TE_{111} mode in this configuration is studied. It is also seen that the slot geometry and offset can be optimized to excite the higher order TM_{101} mode. Ansoft HFSS is used to analyze the proposed antenna configuration. The proposed antenna can be applied to IEEE802.11 WLAN systems.

Keywords: Dielectric resonator antenna, Inclined slot, Offset slot, Microstrip slot

Biography

Mahesh Singh is a Ph.D. student in Dept. of Electronics and Electrical Communication Engineering at Indian Institute of Technology Kharagpur. Mr. Singh received the Master of Technology (M.Tech) degree in specialization of RF and Microwave Engineering under Dept. of Electronics and Electrical Communication Engineering at Indian Institute of Technology Kharagpur in 2015 and Bachelor of Technology (B. Tech) degree from Dept. of Electronics and Communication Engineering at Asansol Engineering College, West Bengal, India in 2011. His research is supported by MHRD, Govt. of India and his current research primarily involves Dielectric Resonator Antennas (DRAs) and Leaky Wave Antennas (LWAs). Also he holds a graduate student membership and Antennas and Propagation Society Membership in IEEE.

Bratin Ghosh (M’05) received the B.E. degree in electronics and telecommunication engineering from Jadavpur University, Kolkata, India, in 1990, the M.Tech. degree in microwave engineering from the Indian Institute of Technology, Kharagpur, India, in 1994, and the Ph.D. degree in applied electromagnetics from the University of Manitoba, Winnipeg, MB, Canada, in 2002. He did his postdoctoral research from the Royal Military College, Kingston, ON, Canada from September 2002 to December 2003. He is currently an Associate Professor in the Department of Electronics and Electrical Communication Engineering, Indian Institute of Technology. His research interests are efficient antennas, antenna miniaturization, metamaterials, guided-wave components, and numerical techniques.

Outline

- Dielectric resonator antenna (DRA) overview
- Different types of fed to DRA
- Various Modes excitation in slot fed DRA
- Parametric variations of slot fed DRA
- Conclusions
- References

DRA Overview

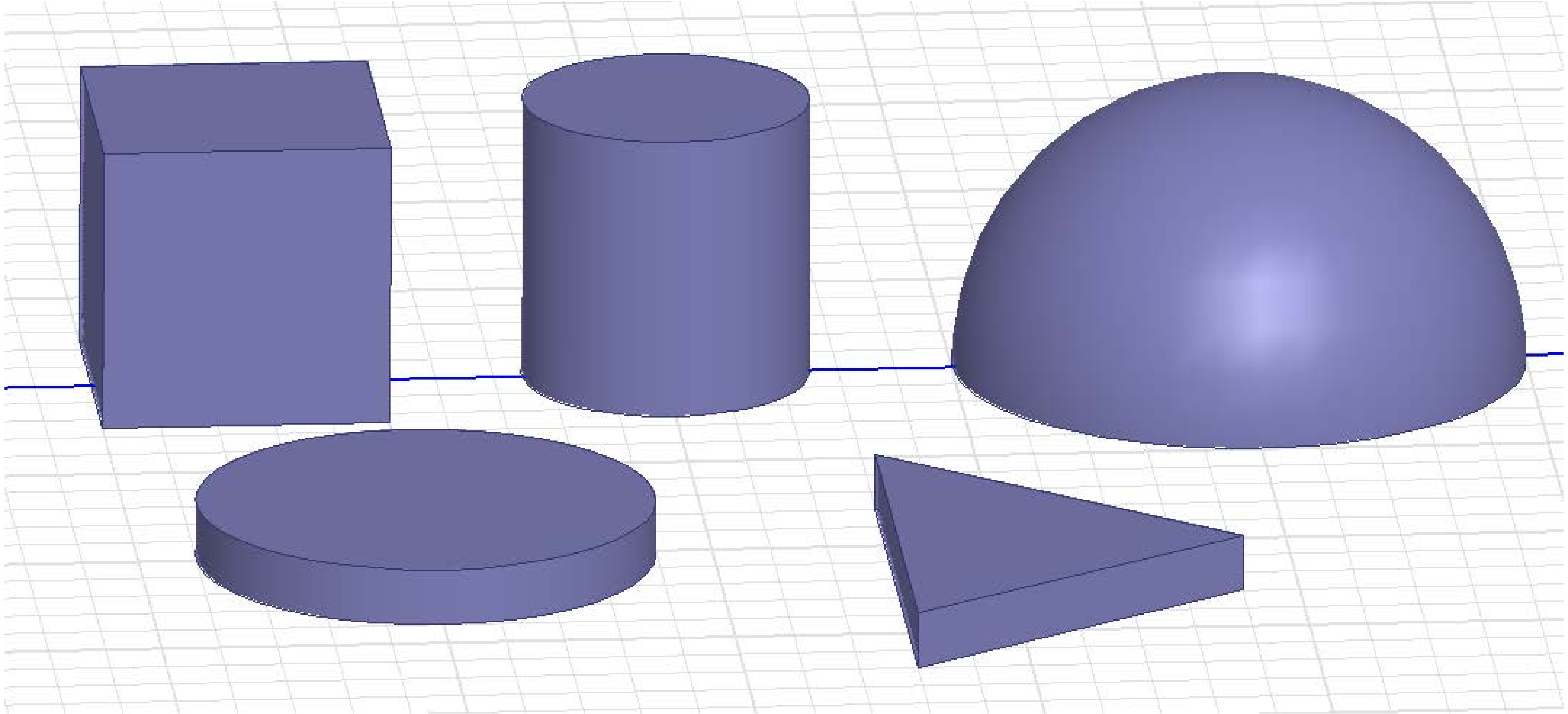
- Traditionally dielectric resonator (DR) used in microwave circuits, such as oscillators and filters.
- Where DR is normally made of high permittivity material, with dielectric constant $\varepsilon_r > 20$, usually treated as energy storage device.
- If less value of dielectric constant used then DR can be used as radiator rather than energy storage device.
- Size of the DRA is proportional to $\lambda_o/\sqrt{\varepsilon_r}$, where λ_o is free space wavelength at resonant frequency, and ε_r is the dielectric constant of the material. So antenna militarization can be achieved with DRA.
- High radiation efficiency can be maintain even at millimetre wave frequency, due to absence of surface wave and minimal conductor losses associated with the DRA.

DRA Overview

- High power capability, as the dielectric constant is high.
- Wideband especially as compared to microstrip antennas, with some geometries achieving bandwidths of 50% or even higher.
- Can be of low profile, as for some geometries their height can be as small as 0.05λ .
- Can be used in a wide range of applications, including mobile wireless communication, satellite systems, GPS, and indoor communications.

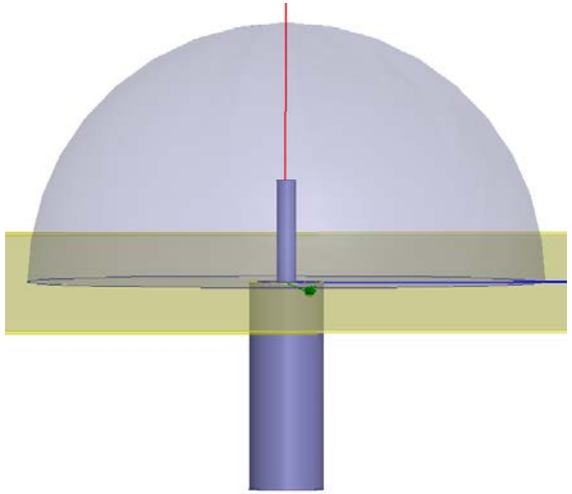
DRA Shapes

- ❑DRA can be of various shapes such as rectangular, cylindrical, hemispherical, low profile circular disk, low profile triangular disk

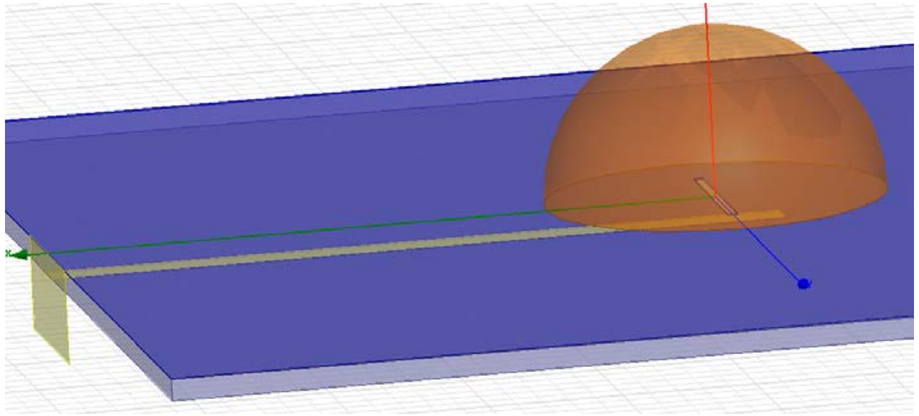


DRA feeds

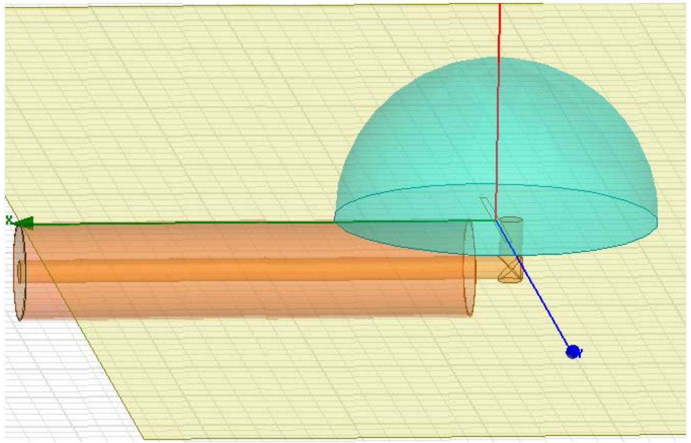
- ❑DRA can be fed with number of ways such as coaxial probe, aperture coupled with microstrip feedline, aperture coupling with coaxial feedline, coplanar feed and conformal strip feed.



coaxial probe
feedline



aperture coupled
with microstrip
feedline



aperture coupling
with coaxial feedline

Modes in Hemispherical DRA

- ❑The modes in dielectric sphere can be divided into transverse electric (TE) and transverse magnetic (TM) modes.
- ❑The TE modes is characterised by having zero value for the radial component of the electric field $(E_r = 0)$.
- ❑ The TM modes is characterised by having zero value for the radial component of the magnetic field $(H_r = 0)$.
- ❑There are two fundamental modes in hemispherical DRA (HDRA), TE_{111} and TM_{101} modes.
- ❑ TE_{111} whose radiation pattern is similar to that of a short horizontal magnetic dipole.
- ❑ TM_{101} whose radiation pattern is similar to that of a short vertical electric monopole.

Characteristics equation for DRA [15]

- For TE_{nmr} mode

$$\frac{J_{n-1/2}(kr)}{J_{n+1/2}(kr)}=\frac{H^{(2)}_{n-1/2}\left(\frac{kr}{\sqrt{\varepsilon_{ra}}}\right)}{\sqrt{\varepsilon_{ra}}\,H^{(2)}_{n+1/2}\left(\frac{kr}{\sqrt{\varepsilon_{ra}}}\right)}$$

- For TM_{nmr} mode

$$\frac{n}{kr}-\frac{J_{n-1/2}(kr)}{J_{n+1/2}(kr)}=\frac{n\varepsilon_{ra}}{kr}-\sqrt{\varepsilon_{ra}}\,\frac{H^{(2)}_{n-1/2}\left(\frac{kr}{\sqrt{\varepsilon_{ra}}}\right)}{H^{(2)}_{n+1/2}\left(\frac{kr}{\sqrt{\varepsilon_{ra}}}\right)}$$

- The resolution in

$$ka=X-jY=\frac{\sqrt{\varepsilon_{ra}\mu_{ra}}}{c}\,a\left(\omega'-j\omega''\right)$$

J - First kind of Bessel function
$H_n^{(2)}$ - Second kind of Hankel function
a - Radius of dielectric sphere
ε_{ra} - Permittivity of dielectric sphere
μ_{ra} - Permeability of dielectric sphere
k - wave number
ω - Complex radian frequency

Source Free Resonant frequency for Hemispherical DRA [16]

- Characteristics equation for TE_{111} is given by

$$\frac{J_{1/2}(\sqrt{\varepsilon_{ra}}k_o a)}{J_{3/2}(\sqrt{\varepsilon_{ra}}k_o a)} = \frac{H_{1/2}^{(2)}(k_o a)}{\sqrt{\varepsilon_{ra}}H_{1/2}^{(2)}(k_o a)}$$

Resonant frequency, $f_{GHz} = \dfrac{4.7713\mathrm{Re}(k_o a)}{a_{cm}}$, where, $\mathrm{Re}(k_o a) = 2.8316\varepsilon_{ra}^{-0.47829}$

- Characteristics equation for TM_{101} is given by

$$\frac{1}{\sqrt{\varepsilon_{ra}}k_o a} - \frac{J_{1/2}(\sqrt{\varepsilon_{ra}}k_o a)}{J_{3/2}(\sqrt{\varepsilon_{ra}}k_o a)} = \frac{\sqrt{\varepsilon_{ra}}}{k_o a} - \sqrt{\varepsilon_{ra}}\frac{H_{1/2}^{(2)}(k_o a)}{H_{3/2}^{(2)}(k_o a)}$$

Resonant frequency, $f_{GHz} = \dfrac{4.7713\mathrm{Re}(k_o a)}{a_{cm}}$

where, $\mathrm{Re}(k_o a) = 4.477226\varepsilon_{ra}^{-0.505}$

J - First kind of Bessel function
$H_n^{(2)}$ - Second kind of Hankel function
a - Radius of dielectric sphere
ε_{ra} - Permittivity of dielectric sphere
k_o - Free space wave number

Source Free Resonant frequency for Hemispherical DRA

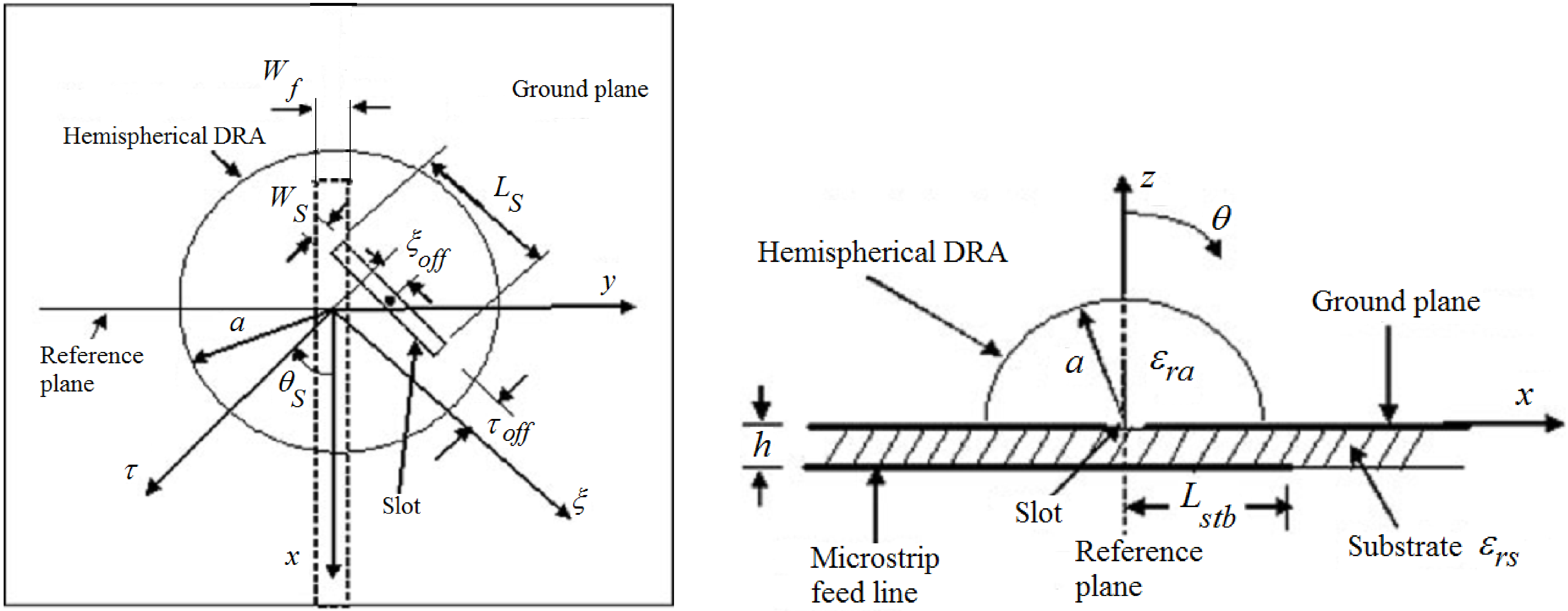
For, $a = 1.27 cm$

$\varepsilon_{ra} = 20$

Resonant frequency for TE_{111} =2.5386 GHz

Resonant frequency for TM_{101} =3.705 GHz

Antenna configuration

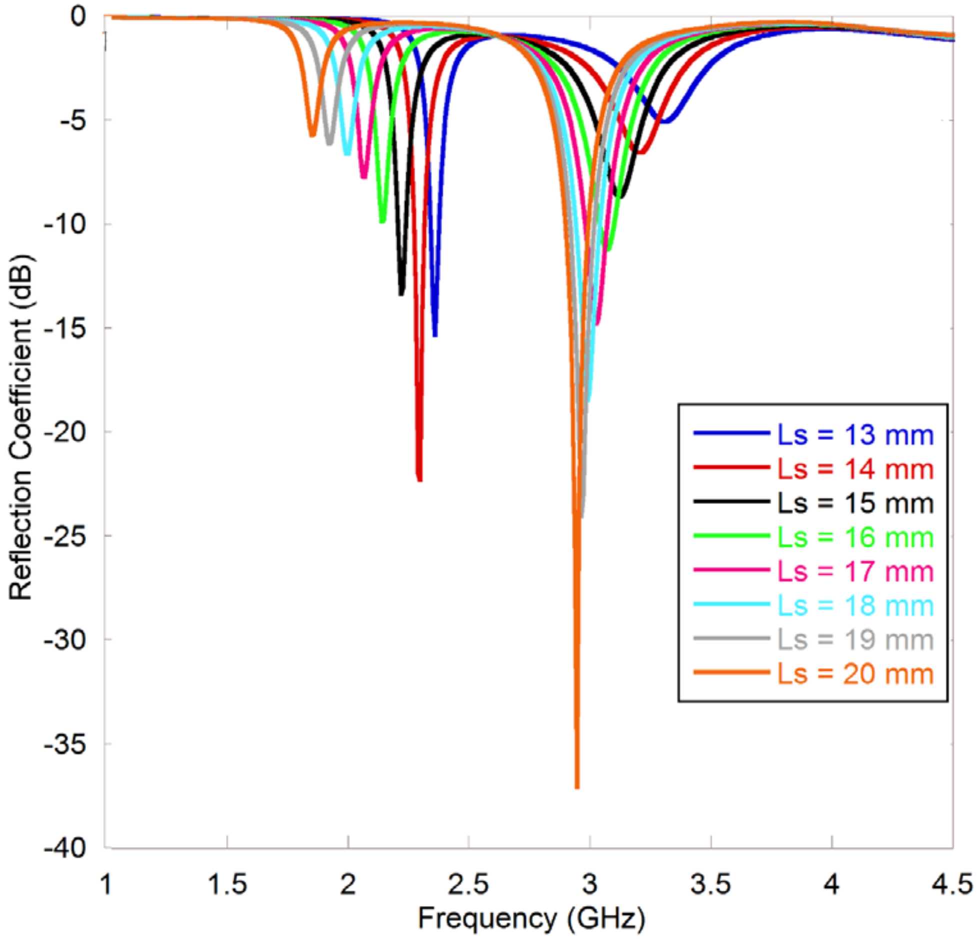

W_f
Ground plane
Hemispherical DRA
W_S
L_S
ξ_{off}
y
a
Reference plane
θ_S
τ_{off}
τ
Slot
ξ
x
z
θ
Hemispherical DRA
Ground plane
a
ε_{ra}
x
h
Slot
L_{stb}
Microstrip feed line
Reference plane
Substrate ε_{rs}

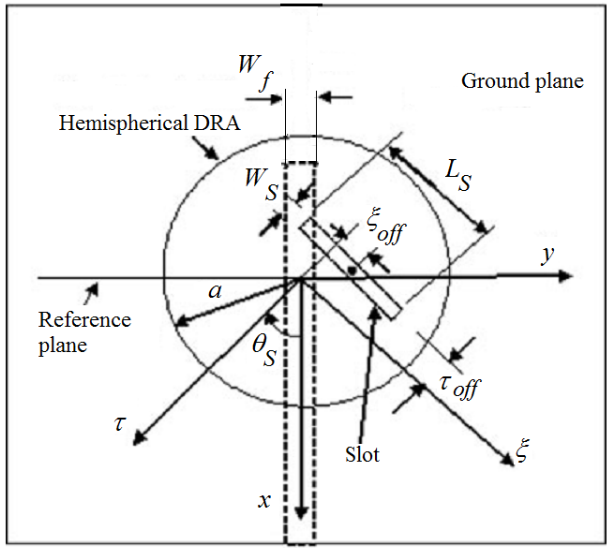
(a)

(b)

Geometry of the microstrip feedline inclined slot coupled hemispherical DRA (a) Top view, (b) side view.

Reflection coefficient for microstrip slot-coupled HDRA for various slot length L_S




W_f
Ground plane
Hemispherical DRA
L_S
W_S
ξ_{off}
y
a
Reference plane
θ_S
τ_{off}
τ
Slot
ξ
x

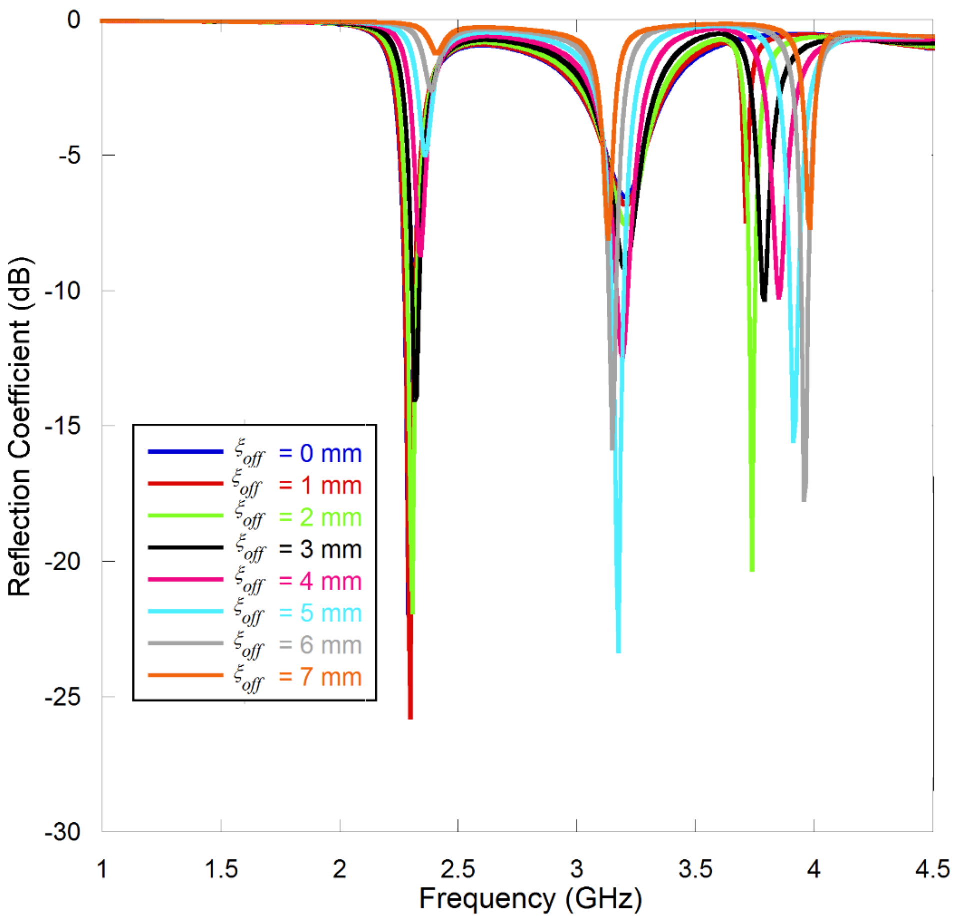
$W_S = 0.7mm, a = 12.7mm, \varepsilon_{ra} = 20,$

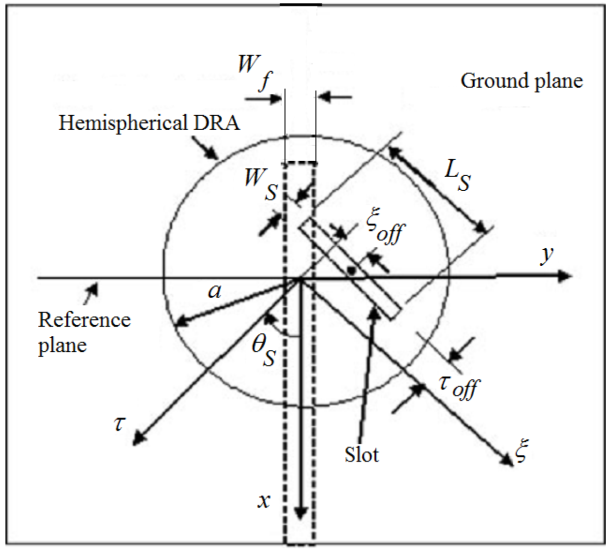
$\varepsilon_{rs} = 4.4, h = 1.58mm, W_f = 3.1mm,$

$\tau_{off} = 0mm, \xi_{off} = 0mm, \theta_S = 0^\circ,$

$L_{stb} = 5mm$

Reflection coefficient for microstrip slot-coupled HDRA for various ξ_{off}

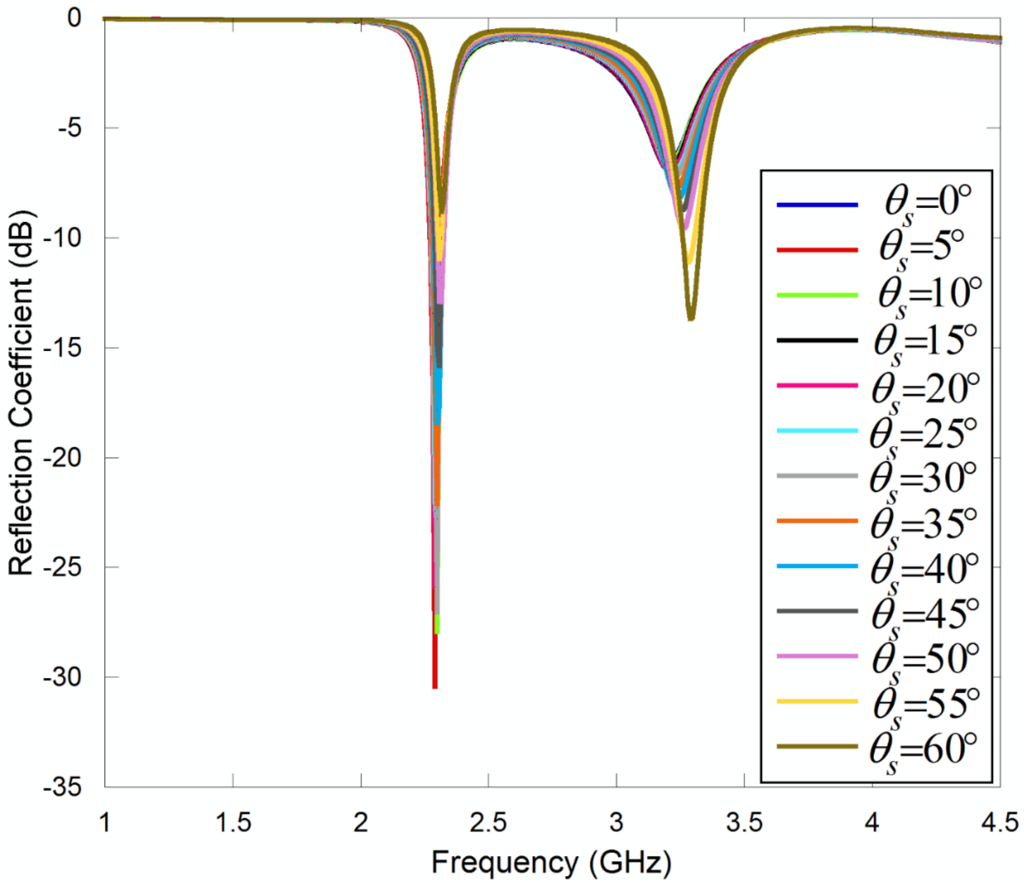


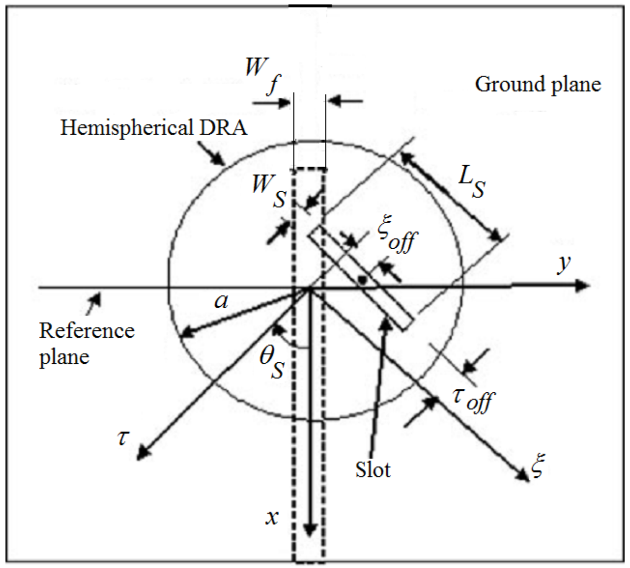

W_f
Ground plane
Hemispherical DRA
L_S
W_S
ξ_{off}
y
a
Reference plane
θ_S
τ_{off}
τ
Slot
ξ
x

$L_S = 14mm, W_S = 0.7mm, a = 12.7mm,$
$\varepsilon_{ra} = 20, \varepsilon_{rs} = 4.4, h = 1.58mm,$
$W_f = 3.1mm, \tau_{off} = 0mm, \theta_S = 0°,$
$L_{stb} = 5mm$

- For ξ_{off} up to 3mm resonance is coming due to TE_{111} mode and after ξ_{off} = 3mm next higher order mode TM_{101} is also excited.

Reflection coefficient for microstrip slot-coupled HDRA for various inclination angle θ_S




W_f
Ground plane
Hemispherical DRA
W_S
L_S
ξ_{off}
y
a
Reference plane
θ_S
τ
τ_{off}
Slot
ξ
x

$L_S = 14mm, W_S = 0.7mm, a = 12.7mm,$

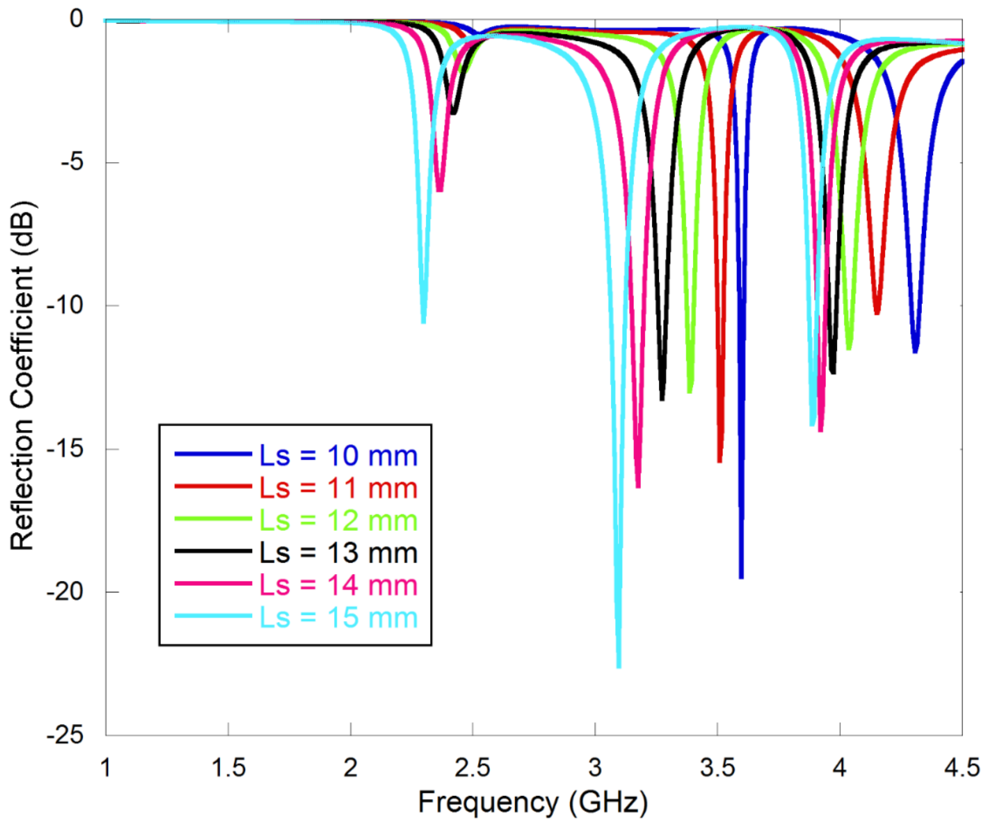
$\varepsilon_{ra} = 20, \varepsilon_{rs} = 4.4, h = 1.58mm,$

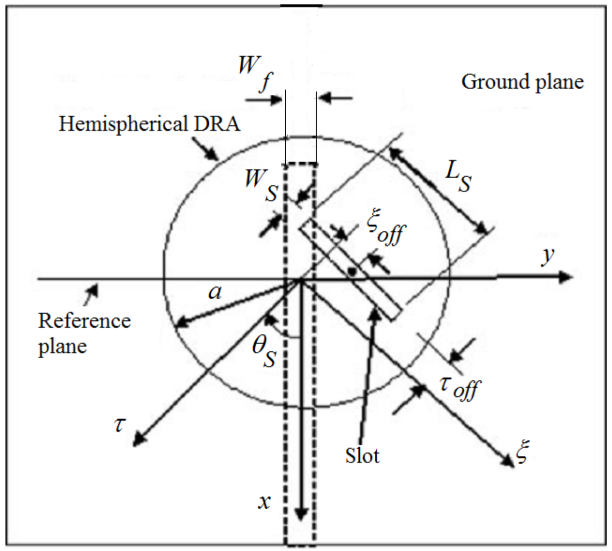
$W_f = 3.1mm, \tau_{off} = 0mm, \xi_{off} = 0mm,$

$L_{stb} = 5mm$

- The resonant frequency 2.29 GHz is unaltered with change in the slot inclination.
- Thus the slot inclination can be used as an impedance matching parameter to match the DRA to the feedline.

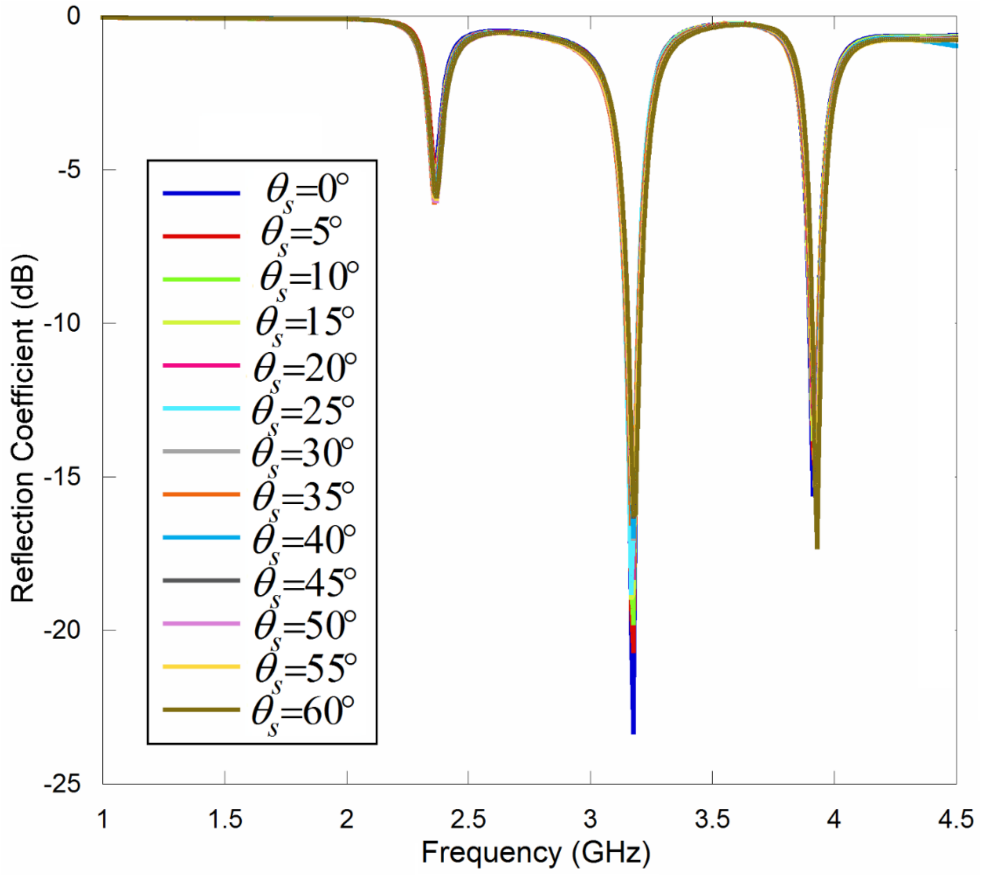
Reflection coefficient for microstrip slot-coupled HDRA for various slot length L_S

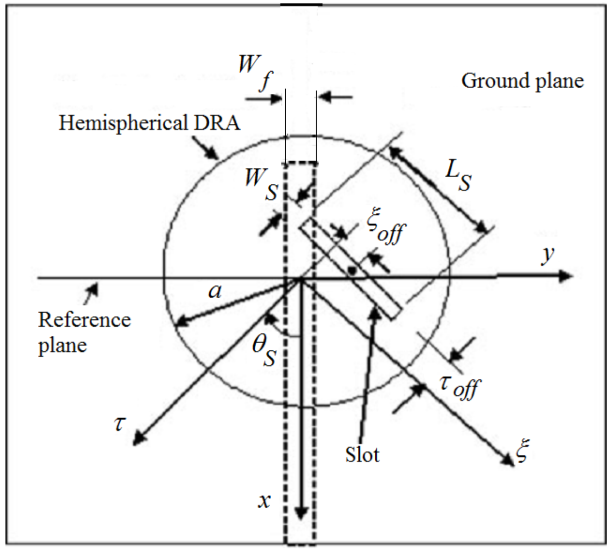



W_f
Ground plane
Hemispherical DRA
W_S
L_S
ξ_{off}
y
a
Reference plane
θ_S
τ_{off}
τ
Slot
ξ
x

$$W_S = 0.7mm, a = 12.7mm, \varepsilon_{ra} = 20,$$
$$\varepsilon_{rs} = 4.4, h = 1.58mm, W_f = 3.1mm,$$
$$\tau_{off} = 0mm, \xi_{off} = 5mm, \theta_S = 45^\circ,$$
$$L_{stb} = 5mm$$

Reflection coefficient for microstrip slot-coupled HDRA for various inclination angle θ_S



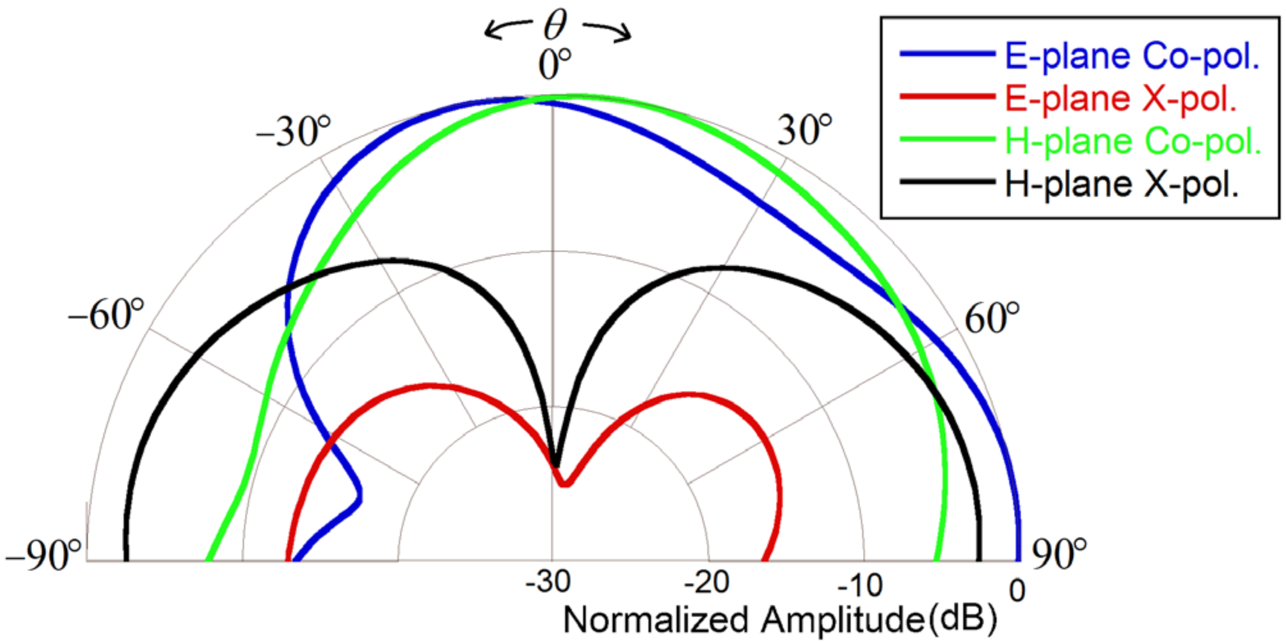


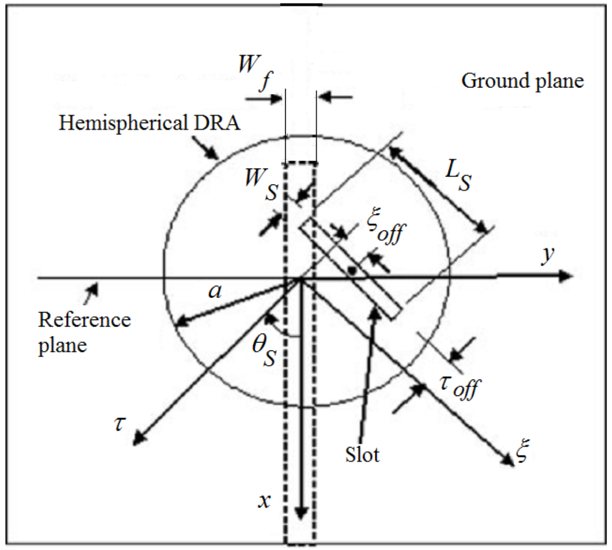
W_f
Ground plane
Hemispherical DRA
W_S
L_S
ξ_{off}
y
a
Reference plane
θ_S
τ_{off}
τ
Slot
ξ
x

$$L_S = 14mm, W_S = 0.7mm, a = 12.7mm,$$
$$\varepsilon_{ra} = 20, \varepsilon_{rs} = 4.4, h = 1.58mm,$$
$$W_f = 3.1mm, \tau_{off} = 0mm, \xi_{off} = 5mm,$$
$$L_{stb} = 5mm$$

- The resonant frequency is unaltered with change in the slot inclination.

Simulated *E* and *H*-plane radiation patterns for microstrip slot-coupled DRA for no inclined slot angle and with no offset.





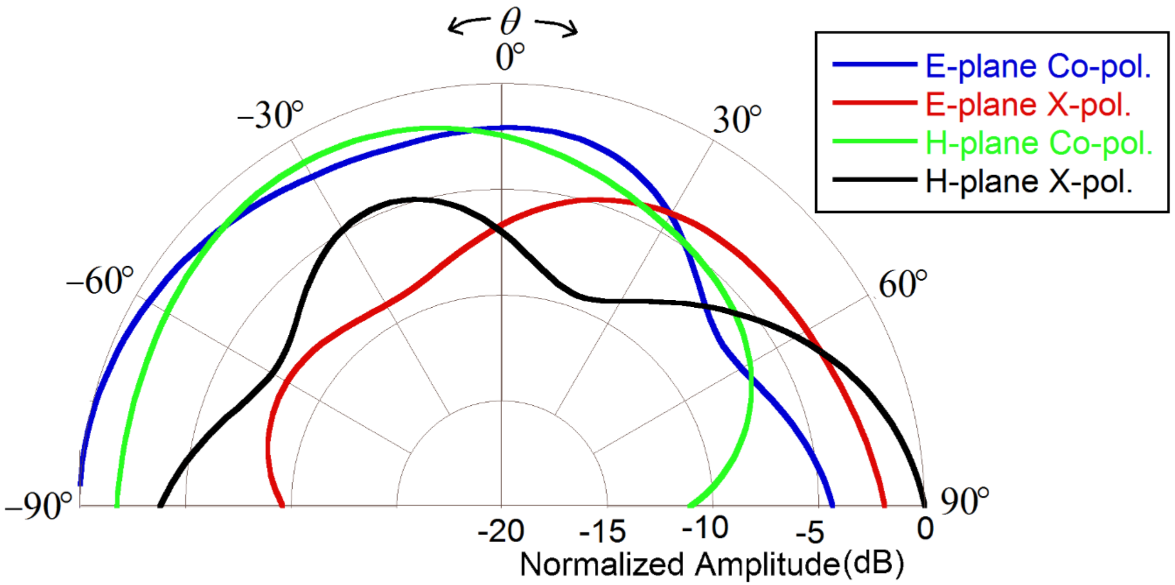
W_f
Ground plane
Hemispherical DRA
W_S
L_S
ξ_{off}
y
a
Reference plane
θ_S
τ
τ_{off}
Slot
ξ
x

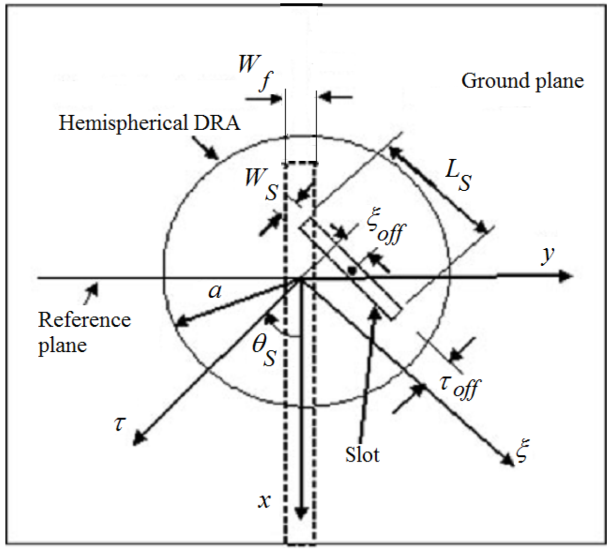
$$L_S = 14mm, W_S = 0.7mm, a = 12.7mm,$$
$$\varepsilon_{ra} = 20, \varepsilon_{rs} = 4.4, h = 1.58mm,$$
$$W_f = 3.1mm, \tau_{off} = 0mm, \xi_{off} = 0mm,$$
$$L_{stb} = 5mm, \theta_S = 0^\circ$$

At resonance frequency 2.298 GHz

Gain = 5.69dB

Simulated *E* and *H*-plane radiation patterns for microstrip slot-coupled DRA for inclined slot angle and with no offset.





W_f
Ground plane
Hemispherical DRA
W_S
L_S
ξ_{off}
y
a
Reference plane
θ_S
τ_{off}
τ
Slot
ξ
x

At resonance frequency 2.307 GHz.

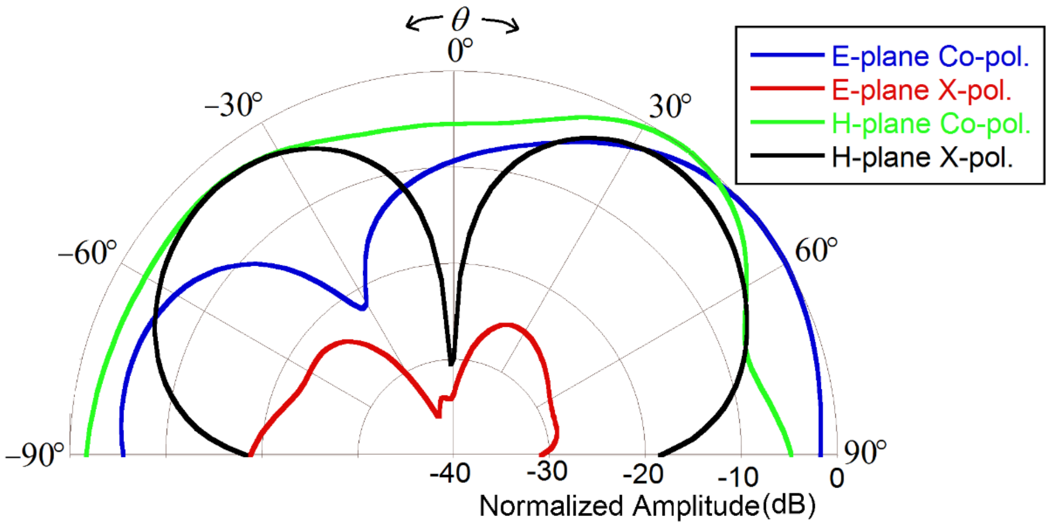
$L_S = 14mm, W_S = 0.7mm, a = 12.7mm,$

$\varepsilon_{ra} = 20, \varepsilon_{rs} = 4.4, h = 1.58mm,$

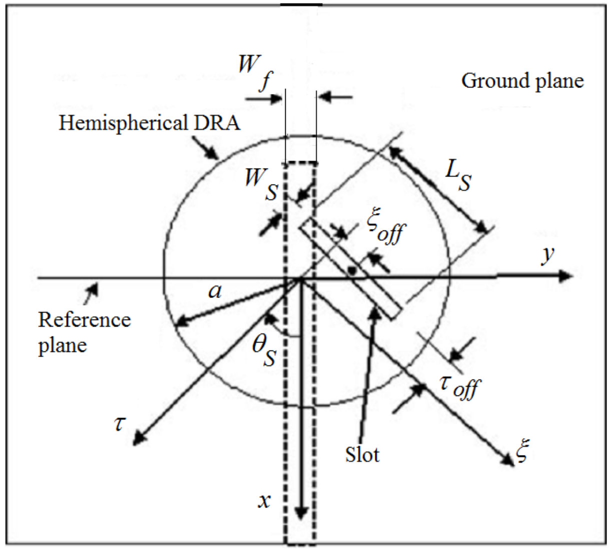
$W_f = 3.1mm, \tau_{off} = 0mm, \xi_{off} = 0mm,$

$L_{stb} = 5mm, \theta_S = 45^\circ$

Simulated *E* and *H*-plane radiation patterns for microstrip slot-coupled DRA for no inclined slot angle and with offset slot.

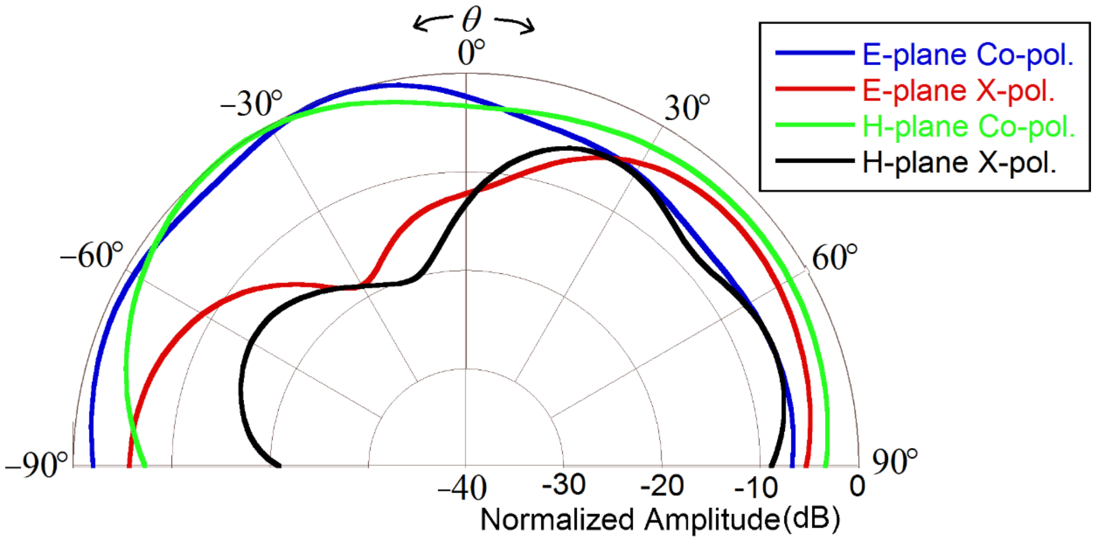


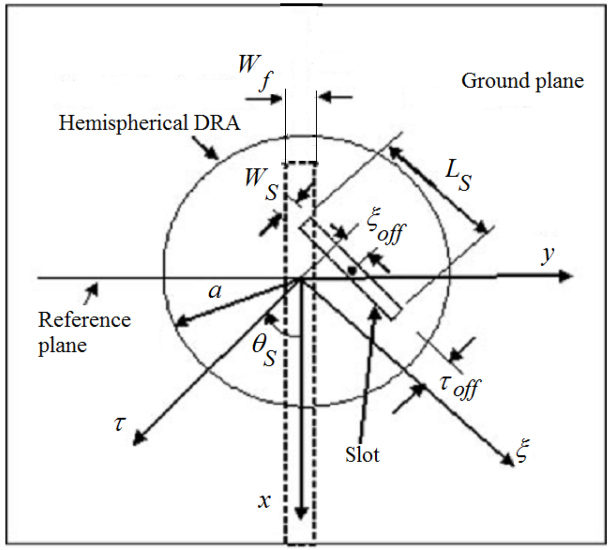
At resonance frequency 3.175 GHz


W_f
Ground plane
Hemispherical DRA
W_S
L_S
ξ_{off}
y
a
Reference plane
θ_S
τ_{off}
τ
Slot
ξ
x

$$L_S = 14mm, W_S = 0.7mm, a = 12.7mm,$$
$$\varepsilon_{ra} = 20, \varepsilon_{rs} = 4.4, h = 1.58mm,$$
$$W_f = 3.1mm, \tau_{off} = 0mm, \xi_{off} = 5mm,$$
$$L_{stb} = 5mm, \theta_S = 0^\circ$$

Simulated *E* and *H*-plane radiation patterns for microstrip slot-coupled DRA for inclined slot angle and with offset slot.





W_f
Ground plane
Hemispherical DRA
L_S
W_S
ξ_{off}
y
a
Reference plane
θ_S
τ_{off}
τ
Slot
ξ
x

At resonance frequency 3.175 GHz.

$$L_S = 14mm, W_S = 0.7mm, a = 12.7mm,$$
$$\varepsilon_{ra} = 20, \varepsilon_{rs} = 4.4, h = 1.58mm,$$
$$W_f = 3.1mm, \tau_{off} = 0mm, \xi_{off} = 5mm,$$
$$L_{stb} = 5mm, \theta_S = 45^\circ$$

Conclusions

- ☐ A parametric variation of inclined and offset slot coupled hemispherical DRA excited with the microstrip line has been studied.
- ☐ It is seen that good coupling to the TE_{111} mode of the DRA can be achieved for a centrally located slot with the slot inclination angle less than 60°.
- ☐ The reflection coefficient show almost no change in the resonance frequency with slot inclination.
- ☐ The microstrip stub length has to be adjusted to tune out the slot impedance with varying inclination of the slot.
- ☐ The higher order TM_{101} mode of the DRA excited by displacing the slot along the slot-length axis and by proper optimization of the slot-length.
- ☐ The resonance frequency of the TM_{101} mode, like the case of the TE_{111} mode, is independent of the slot inclination, with the resonance characteristics degraded beyond a slot inclination angle $\theta_S = 60^\circ$.
- ☐ It was also found that the excitation of other higher order DRA modes is possible by proper selection of the slot-inclination, slot-offset and slot-length.
- ☐ It is also observed that for inclined and offset slot cross-pol levels is considerably higher.

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Thank you!!